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A Critical Review and Future Perspective of Hydrate Mitigation Technologies

Bhalchandra Shingan[1], P. Vijay[2]
[1,2]Department of Chemical Engineering, School of Engineering, University of Petroleum andEnergy Studies, Dehradun, Uttarakhand, India 248007.
bhalchandra@gmail.com[1]

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Abstract:
In petroleum studies, one of the notable challenges involves low assurance. In the past 100 years, one of the flow assurance problems that have dominated the field has been documented to involve deep sub-sea pipelines' natural gas hydrates (NGH). For the formation of hydrates, favorable conditions include low temperature and high pressure. Therefore, the need to understand hydrate blockages arises from safety concerns, especially due to the need to ensure that safety is assured. Upon the formation of NGH plugs, pipelines tend to shut down. The gas sector ends up incurring millions of dollars daily while grappling with this hydrate blockage problem. Currently, the most common approaches to preventing NGH plugs include thermal heating and thermodynamic inhibitors. Despite their widespread usage, however, these techniques are impractical in deep water operations and have also proved to be environmentally unfriendly and uneconomical due to their cost-intensiveness. Thus, there is a need for contemporary methods through which issues affecting flow assurance could be addressed adequately, especially in environments where conditions continue to favor hydrate formation. It is also notable that in the petroleum sector, there is a paradigm shift in such a way that efforts are geared towards hydrate management, rather than prevention. The aim is to reduce plugging risks. Similarly, multiphase frameworks exhibiting the kinetics of hydrate formation are deemed relevant in supporting strategies of hydrate management. in this paper, the central purpose lies in the review of some of the technologies that have been employed towards hydrate mitigation at the industrial level. The objective is to discern the effectiveness of the selected techniques.

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I. INTRODUCTION

In sub-sea petroleum environments, the main problem involves flow assurance, especially in regions with cold climate. One of the specific issues that are common and hindering the realization of flow assurance involves wax. In denser components such as napthenes and paraffin, there is likely to be wax precipitation [1]. Also, a problem felt in these environments involves the existence of asphaltenes [2]. These materials exist in crude oil along saturated hydrocarbons, aromatic compounds, and resins, including alkenes too. When pressure and temperature conditions are favorable, the materials exist in the form of colloidal suspension or solution forms. When there is a change in temperature and pressure, which cause primary depletion, there is a precipitation of asphaltenes due to the destabilization of colloidal suspension. Hence, asphaltenes tend to lose stability due to gas injection and fluid blending in a quest to enhance the recovery of oil [3]. It is further notable that the production of asphaltenes accrues from pressure difference in the production system [4]. Another issue that these environments face involves slugging. In riser systems and flow lines, slugging is experienced because of permissive oil and gas flow rates in which there are lower pressures in

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reservoirs, as well as a decrease in the rate of production of the oil and gas materials. Stages responsible for the formation of slug include the buildup of liquids, the formation of slug, the penetration of gases, the blow down of gases, the corrosion process,

Apart from slugging, another issue involves emulsion. Indeed, crude oil-related emulsion arises during the transportation of waxy crude oil. In this case, the resins present in the oil and a polar compound in the form of asphaltenes are responsible for emulsion formation [5]. Of importance to note is that the resultant emulsions tend to increase material viscosity, exceeding that of the otherwise waxy crude oils [6]. Similarly, the problem of erosion has been documented in these environments [7]. The erosion arises from the presence of sands, which causes pipeline blockage in the end, as well as issues such as reduced efficiency of separation and material loss [8]. Indeed, the erosion is mostly attributed to the presence of sand in the production facilities. The removal of such sands requires screens in horizontal parts of the oil production wells. Should this procedure fail, sand access transmission lines, cause pipeline erosion issues. it is important to note that in production systems, flow parameters' real-time monitoring is important because it aides in reducing the problems affecting flow assurance significantly [9]. To achieve this process of solving the issues, several optic sensors have been developed and implemented, handling the perceived flow assurance-related challenges effectively [10].

When gas hydrates form in pipelines, this flow assurance issue is so difficult that addressing it requires much attention and effective techniques. To ensure that multiphase flow transportation and production systems are developed economically, the need to understand the existence of hydrates and the methods of controlling or managing them could not be overstated. Another problem that has been documented in the oil and gas production environments, which affects flow assurance, involves the presence of natural gas hydrate (NGH). From the literature, temperatures less than nine degree Celsius are ideal for ice-like solid particle formation, especially when chlorine is present and exists in an aqueous form.

For the case of natural gas, it has been documented to be a mixture of hydrocarbons. These hydrocarbons include elements such as propane, ethane, and methane, as well as other higher hydrocarbons. Indeed, structural and equilibrium characteristics of these elements differ from each other. For instance, structure II hydrate emanates from propane, which constitutes large molecules [2]. On the other hand, structure I hydrates arises from the main component in the form of methane.

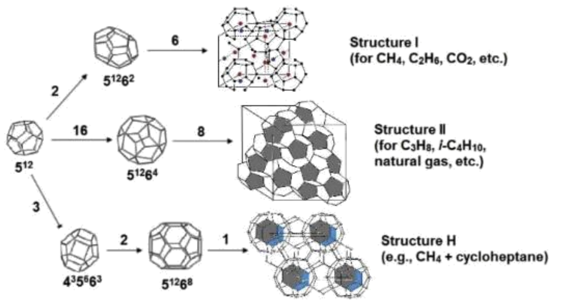

Fig.1. Three common hydrate crystal structures [4]

II. Impact of Hydrates on NGH Transportation

In a given pipeline, there is likely to be massive corrosion, should there be hydrate formation. Broad categories into the effects are places include pipeline stability, environmental effects, and financial effects. From a financial perspective, it has been asserted that when hydrates form, they tend to cause partial pipeline plugging, especially due to the buildup of pressure, which could worsen and cause total pipeline blockage. Therefore, the resultant serious risk to equipment and occupational safety and health implies that this formation of hydrates demands massive expenditures to restore the functionality of pipelines and also maintain them [4].

Other investigations have focused on the impact of hydrates on NGH transportation from an

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environmental perspective. For these studies, hydrate formation tends to cause pipeline failure. In turn, there could be a leakage of fluid content into the surrounding environments. The leakage translates into environmental problems such as explosion and dispersion, besides interfering with the aquatic life by reducing oxygen supply and flow in water [6]. For studies that have examined this impact from the perspective of pipeline stability, it has been acknowledged that hydrate formation causes pipeline deformation, especially because of gas hydrate dissociation. With continued increase in the area of dissociation, the eventuality is that there is massive increase in the amount of sediments deposited, as well as the magnitude of pipeline deformation. The secondary impact of this interference with pipeline stability due to hydrate formation is that there could be an increase in the shear strain and stress; hence, an unstable pipeline [8, 10].

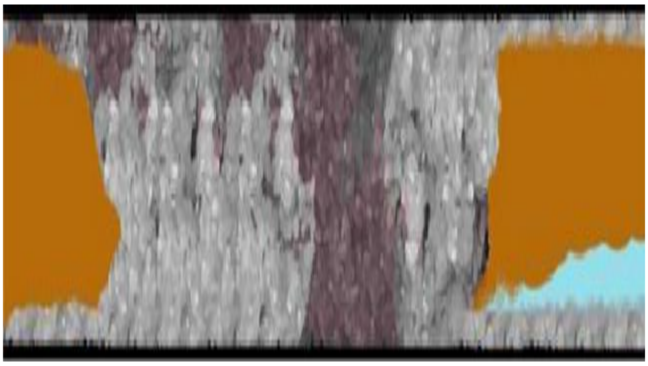

Fig. 2. Hydrate Blockage in pipeline [5]

III. Factors Affecting Hydrate Formation

One of the factors documented to contribute to the formation of hydrates involves pressure. Another factor involves the presence of water, as well as the parameter of temperature. Also, the aspect of gas composition has been affirmed to play a contributory role towards information the formation of hydrates. The following figure shows the hydrate equilibrium curve.

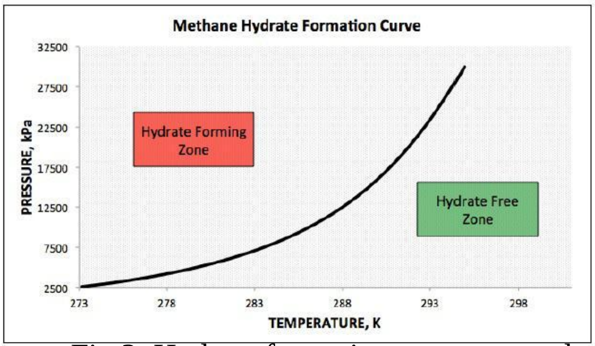

Fig.3. Hydrate formation pressures and temperatures for Methane [6]

IV. Addressing Hydrate Formation

One of the techniques that have been affirmed to support the process of avoiding or minimizing hydrate formation involves the removal of water supply [10]. Particularly, it has been documented that upon ensuring that sufficient water amount is removed from gas and oil in the production systems, hydrate is unlikely to form in the target pipelines. Other studies avow that hydrate formation could be prevented via depressurization [4, 6]. For these studies, it is avowed that depressurization ensures that the hydrate equilibrium pressure is reduced. Hence, the technique aids in removing hydrates after they have formed because the pressure is reduced to ensure that the resultant conditions operate below the perceived equilibrium or optimum conditions that would otherwise support hydrate formation. After the pressure is reduced, there is destabilization in the hydrate formation phase. However, it has been cautioned that this procedure is ineffective in icy zones [5]. Also, the procedure has been observed to be disadvantageous in such a way that it takes long to implement successfully or ensure that the hydrate dissociation process is achieved successfully.

A mechanical procedure has also been proposed as one of the ideal approaches for reducing hydrate formation [3]. In this approach, there is the implementation of a pigging process in such a way that engineered solids are crossed over through pipelines, especially to inspect the

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pipeline cleaning process. For hydrate removal, however, the approach has been documented to be ineffective because it ends up compressing the hydrate blockage and, in turn, complicating the system. Critical issues are also likely to result when the procedure is implemented in situations where blockages have not developed fully in the pipelines.

Hydrate mitigation technology has also been investigated in terms of thermal methods. One of the specific approaches include wet insulation. As mentioned earlier, environmental conditions in deep waters tend to favor hydrate formation, with the temperatures of around four degrees Celsius proving ambient. As such, insulating the pipeline transportation systems proves key to the mitigation of hydrate formation [11]. With ambient temperatures being low, there is heat loss in the flow streams and, eventually, the creation of flow assurance issues. Therefore, wet installation via glass reinforced plastics, rubber, or polyurethane via injection, extruding, spraying, or casting ensures that hydration is minimized [12]. However, the material used for wet installation needs to be strong because of the conditions in the sub-sea environment.

Another key procedure for mitigating hydrate formation involves dry insulation [12, 13]. In this method, the resultant system entails pipe-in-pipe insulation. Hence, there is the placement of the insulation material in the two pipes' annuls, with the external pipe protecting the insulation material against contact with foam from destructive hydrostatic pressure elements. Some of the materials deemed appropriate for use in insulation in this arrangement include gels, micro-porous silica, and low-density polyurethane foam.

Table 1
Parameters for subsea thermal insulation material [1]

Materials	k-Value(W/m.K)	Max temp(°C)	Max. depth(m)
Rubber (Neoprene / HNBR)	0.26-0.28	90/140	Unlimited
Filled (Neoprene / HNBR)	0.12-0.14	90/140	Unlimited
Syntactic epoxies	0.12-0.17	110	2185
Polyurethane	0.19-0.20	90 Wet/115 dry	Unlimited
Syntactic polyurethane	0.13	90 Wet/115 dry	300
Polypropylene	0.21-0.26	145	Unlimited
Polypropylene foams	0.13-0.2	145	Unlimited

Another mitigation technique documented to address hydrate formation involves the use of buried and partially buried pipelines. Particularly, the pipelines are buried at the level of the mud line to ensure that rocks are dumped over them. The main processes of burying the pipelines include back lining and trenching. Given that the buried pipeline's heat capacity exceeds that of the pipe-in-pipe arrangement, the cool down time tends to be extended, an outcome that mitigates hydrate formation. It is also notable that the cost of installation for the pipe-in-pipe system is about 35% to 50% higher than that which is used for buried pipelines. For long distance pipelines, therefore, the buried pipelines option has been affirmed to be economical due to its cost-effectiveness. Thus, it emerges as an alternative to the use of pipeline fabrication. It is also notable that the high capacity of the soil implies that it absorbs the buried pipeline's heat. Therefore, the pipe reflects a natural form of heat storage, giving thermal inertia to the entire system [14, 15].

Another mechanism involves the use of active heating methods. In particular, pipeline pigging strives to ensure that hydrates are removed. However, active heating procedures aid in avoiding the pipeline pigging step. Indeed, the

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technique ensures that compared to the temperature of hydrate formation, the fluid's temperature remains higher. Two specific types of active heating methods that have been documented include the circulation of hot fluids and the electrical-heating system. For the case of the electrical-heating system, an electric cable is used for the purpose of providing heat, either in the form of the earthed current system or the electrical insulated system. To design the electrical heating system, major parameters that are worth considering include the temperature of the seawater, the steady state temperature of the pipe that is required, the magnetic and electric behavior of the pipe, the geometrical aspects (such as feeder location and cable and pipe dimension), the pipe insulation and surroundings' thermal properties, the depth of the water and the seabed, and the resistivity of the seawater [16-20].

In relation to the second method of active heating, which constitutes hot fluid circulation, there is the installation of bundled systems to ensure that any wasted heat is utilized, including that which comes from hot water systems and exhaust gases. Given a circulation loop, water is heated using waste heat recovery arrangements before transporting water into bundles. The eventuality is that the temperature is increased.

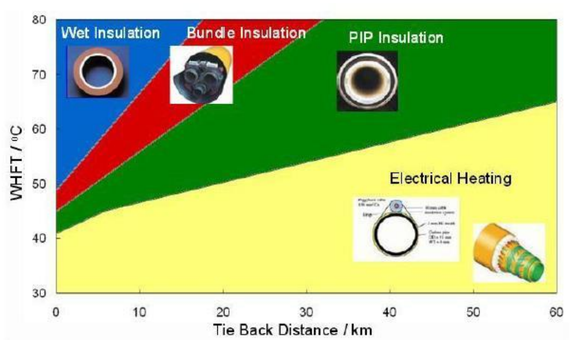

Fig.4. Different Pipe Insulation Types as a Function of Temperature and Tie-Back Distancein Deep water (1500 m) [7]

Another area that is worth examining includes hydrate inhibitors. Particularly, hydrate inhibitors have been affirmed to exhibit several properties. For example, they are expected to be universally used and that they ought to be above certain ranges of concentration. Also, given that the temperature experienced during the production processes is high and ranges from 90 degrees Celsius to 100 degrees Celsius, chemicals that are mixed with the streams, which act as hydrate inhibitors, are expected to be soluble at these high temperatures. Furthermore, the chemicals are expected to be less viscous because high viscosity could make them difficult to inject into the system, as well as increase the cost of material transportation. Conversely, the chemicals used as hydrate inhibitors are expected to be compatible with other materials, compounds, chemicals, or elements within the material being transported, including emulsions, wax, scales, and corrosive products. Lastly, the chemicals used as hydrate inhibitors ought to abide by guidelines governing environmental constraints and waste water toxicity regarding downstream gas and oil flows and firms.

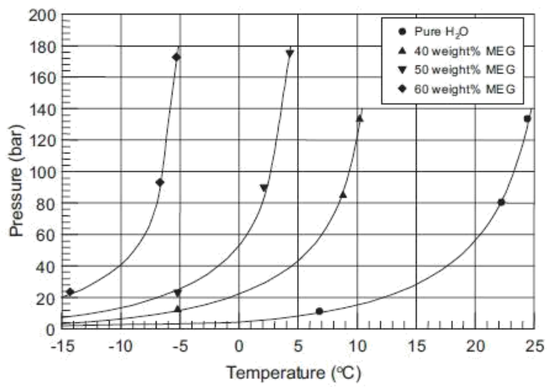

Fig.5.Simulated Hydrate Temperatures by using MEG as a THI [8]

Cold Flow Model: CSMHyK used Gudmundsson's cold flow concept which is already discussed. The transport model is applied for simulation of cold flow concept.CSMHyK presented physical phenomenon of formation hydrate blockage and is divided into four main stages as shown in Fig 5[12].Water entrainment: Water in oil emulsion forms where water droplets are dispersed in oil phase[21-23].

Hydrate growth: A hydrate formation takes place at interface between water and oil phase.
Agglomeration: The particles can agglomerate, increasing into larger hydrate particle size.
Hydrate Blockage: Due to agglomeration of hydrate particles viscosity of mixture increases which can cause hydrate blockage.

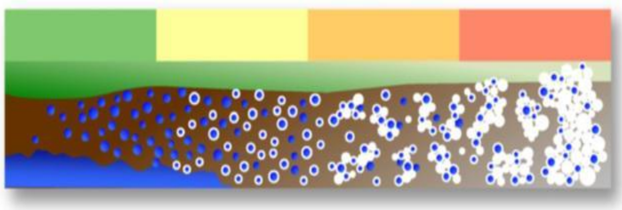

Fig.6. Hydrate plug formation in multiphase flow system [12]

CSMHyK can be convenient tool to estimate the hydrate plug formation conditions. A growth model including mass and heat transfer is useful for more accurate conditions. This research is continued in Colorado School of mines [2].Recent review on literature found that, THIs can be used at low concentra-tion and hydrate slurry can be formed which can be transported with oil, gas and water. In CSIRO Earth Science and Resource Engineering, Australia, Low volume MEG was used to form hydrate slurry which can be transported. In this study, rate of hydrate formations and pressure drop were measured at different system temperatures and sub-cooling. Researchers used a one-inch single pass flowloop which contains aqueous MEG solutions up to 40% and a liquid loading of 5 vol%. Domestic natural gas was used at an initial pressure of 10.3 MPa. Several experiments have been carried out by using under inhibited methanol. It has shown that pressure drop with respect to time was constant. The results of experiments suggest that increasing rate of injection of methanol will reduce hydrate formation rate and transportability of hydrates can be increased. How-ever, at decreasing temperature, if methanol concentration is increased it willcreate sloughing problem. Sloughing means shear breaking of hydrate deposits. In some experiments, average deposition rate was also calculated. Deposition rate was not related to sub cooling like hydrate formation rate [9].Lorenzo M.D. et al.(2014) developed single pass flow loop for hydrate formation in gas-dominated systems in Centre for Energy, School of Mechanical and Chemical Engineering, University of Western Australia. It is named as a Hytraloop. For research a 130 ft single-pass pipeline has been constructed. Annular flow regime was formed in gas condensate pipeline. They have used under inhibited system i. e. low volume of MEG to form hydrate slurry. Hydrates were formed during experiments. The rate of hydrate formation was very fast i.e. 250 times in gas dominated flow than oil dominated flow. When MEG was injected at low volume pressure drop behavior was constant. At constant temperature increasing rate of MEG injection, hydrate formation rate was reduced and transportability of hydrates in increased [14].

V. CONCLUSION

In the oil and gas sector, one of the critical issues that are worth examining involves flow assurance. During the production and transportation of oil and gas productions, the main problem that continues to be reported involves gas hydrate formation. The main aim of this review paper has been to discuss some of the methods of hydrate mitigation and their effectiveness, based on the insights gained from the literature. Indeed, new approaches such as multiphase flow modeling and cold flow technology have been presented. From the results, it can be inferred that the depressurization technique is limited because of safety considerations, making it less ideal for use in NGH removal. However, in situations where the dew point of the water is controlled successfully, effective management of hydrate blockage could be realized. For the case of thermal techniques, it is worth noting that they call for massive energy amounts, making their use cost-intensive and less

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economical. Of importance to acknowledge is that any failure of a thermal technique implies that the aquatic life would be at risk, especially due to possibilities of alterations in the supply and flow of oxygen in water. The most common technique that has been found to gain widespread usage for hydrate mitigation, therefore, involves the use of thermodynamic inhibitors. Despite the promising nature of the thermodynamic injection approach, the chemicals could be poisonous. Also, the method is cost-intensive. Despite these mixed outcomes, an emerging theme is that in the oil and gas sector, there is a notable paradigm shift in the methods of preventing and managing hydrate, especially due to the need to reduce plugging risks. The study's analysis demonstrates that multiphase frameworks and cold flow technology relative to the kinetics of hydrate formation constitute more promising paths through which effective systems for managing hydrates could be designed and implemented. In the future, it is predicted that more promising and cost-effective, as well as environmentally friendly techniques of hydrate management will emerge and strive to counter drawbacks with which previous and current techniques are associated.

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